ENERGY EFFICIENT COMMUNICATION AND COORDINATION FRAMEWORK FOR HETEROGENEOUS WIRELESS SENSOR NETWORKS

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DEDICATION

I dedicate this thesis to my father who always loved and encouraged me.

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I express my gratitude to Almighty Allah for blessing me with wisdom, healthiness and power.

ABSTRACT

With revelation of miniature technologies, sensing devices which are powered with limited batteries and a lot of applications came into existence like applications for mine detection, monitoring of battle field, pollution monitoring, military surveillance, data gathering from remote locations, monitoring of underground mines, health-care, agriculture and smart cities, etc. Sensing nodes are significantly important components of the Wireless Sensor Network (WSN). The major challenge in WSNs is the efficient consumption of node battery with reliable data communication. The energy efficiency is the key component of every routing strategy designed for WSNs. Comparatively more battery consumption takes place during communication on longer and extended distances. Whereas redundant transmissions and less effective selection of routing path between source and destination is also a key contributor towards higher battery dissipation.

In this thesis, an energy efficient communication and coordination framework has been proposed in Heteorogenpus WSN (HtWSN). In HtWSN, an energy-efficient protocol named Threshold-EEhDEEC (T-EEHDEEC) has been developed. For the sake of heterogeneity, three types of nodes have been considered in this work which are normal, advance and super nodes. Furthermore, a novel threshold has been defined to enhance the performance of our proposed protocol. To verify and validate performance of our proposed routing protocol, we have conducted the simulations for energy consumption, packet delivery ratio, and First Node Die (FND). Furthermore, an existing heterogenous communication protocol namely TBEENISH has also been implemented for comparison. The results show that our proposed scheme outperforms over counterparts in terms of energy, FND and packet delivery ratio.

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Acronyms

ADRP Adaptive Decentralized Re-clustering Protocol.

BS Base Station.

CDMA Code-Division Multiple Access.

CH Cluster Head.

DEEC Distributed Energy Efficient Clustering.

EDEEC Enhnced DEEC.

EEHDEEC Energy Efficient Heterogenous DEEC.

GPS Global Positioning System.

HoWSN Homogenous WSN.

HtWSN Heteorogenpus WSN.

ID Identifier.

RSS Received Signal Strength.

SEP Selection Election Protocol.

T-EEHDEEC Threshold-EEhDEEC.

TDMA Time-Division Multiple Access.

TEEN Threshold sensitive Energy Efficient sensor Network.

TWSN Teristial WSN.

UWSN Underwater WSN.

WSN Wireless Sensor Network.

Chapter 1

Introduction

This chapter introduces the basic terminologies and an overview of the Wireless Sensor Network (WSN) and heterogeneous WSN (HtWSN).

1.1 Introduction to WSN

WSNs are composed of intelligent interconnected sensing nodes performing tasks in cooperative ways. These Sensor Nodes (SNs) can be termed as tiny computers, which are capable to sense the environment, collect the information and forward it to either other nodes or some base station. Every SN in such a network is usually characterized by tiny size, limited power, low computation capabilities and wireless access. In order to measure certain characteristics of the environment, a variety of biological, chemical, thermal, mechanical, magnetic and optical sensors are attached to the SN. All nodes in such a network have very limited computational power and their applications are mostly in such areas where it is difficult to access them so a radio is attached. This radio is facilitating the wireless communication to transfer the information collected by nodes to the BS (Base Station) [1].

WSN is a crucial element of ubiquitous computation. Many useful applications are developed with the technology emerges that are helpful for mankind in many purposes. With the increasing demand of WSN in many industries, it is assumed to rise from $0.45 billion approx in 2012 to $2 billion approx in 2022 [2]. The per year annual rise from 2010-2014 is shown in Figure. 1.1 [2].

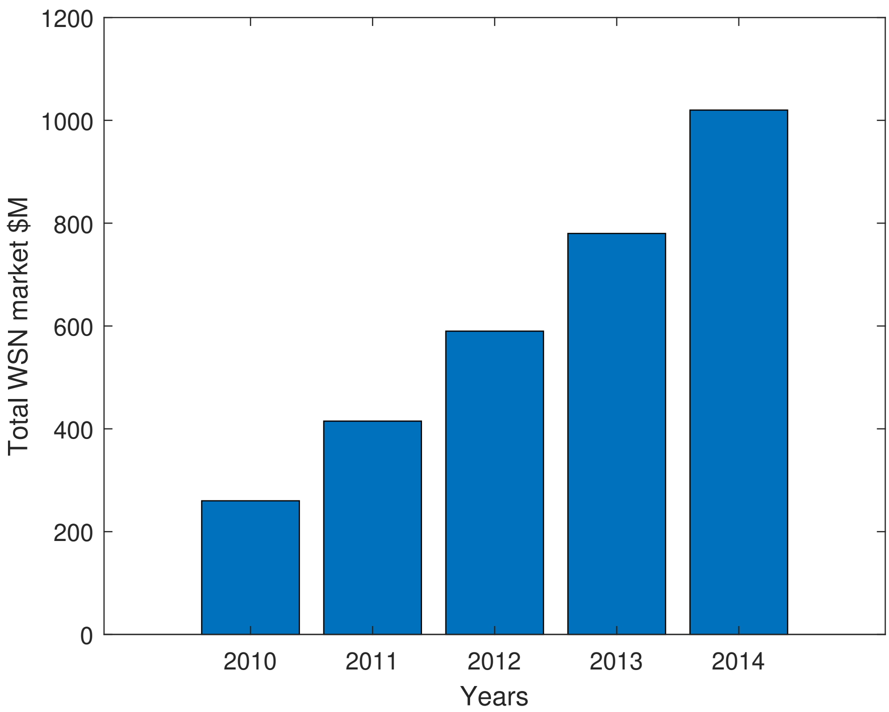

Figure 1.1: WSN annual rise chart from 2010-2014[2]

Many applications in WSN require SNs. For this reason, many SNs are deployed. The first protocol 802.11 was introduced in 1997, which was then upgraded to 802.11b with greater data rate. A common WSN architecture is presented in Fig. 1.2[2], where nodes are deployed at a particular area and the data received by nodes is delivered to sink. The data received by the sink can be used on the internet. The deployment of nodes in WSN are usually random or they are manually placed for achieving the desired objectives. With the technology advances, many SNs are getting smarter with the passage of time which makes the designer to use more number of nodes for communication. Figure 1.3 shows the real time example of SNs, which is developed by Genetlab and it has been used for detection in military applications [3].

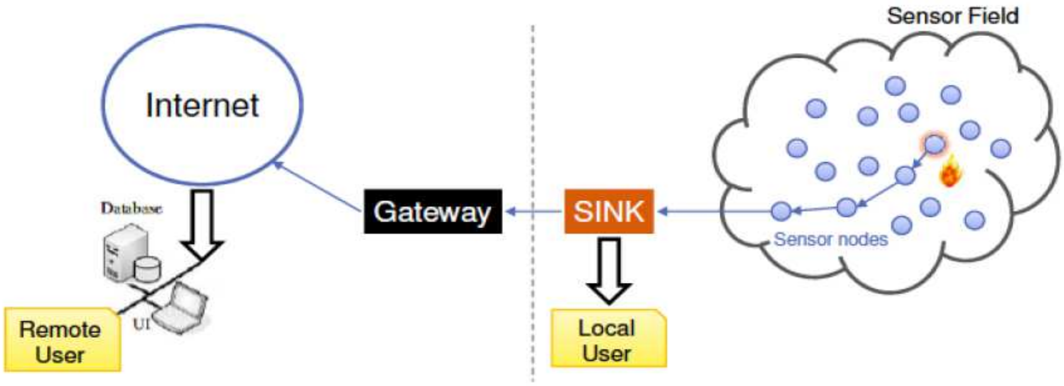

Figure 1.2: A typical WSN architecture[2]

SNs are made up of three basic components. The one is the sensing device that helps to sense the data; the second one is the data processing device that processes the data and stores the information. The last one is the data transmission device, which helps to transmit the data towards the destination. SNs performs direct communication with the sink or uses the relay nodes to deliver data towards the sink. It may run out of energy rapidly while performing direct communication thus reduces the network performance. It may increase the network delay if it adopts hop-by-hop communication i.e., delivers data towards the sink through relay nodes.


Figure 1.3: An example of a common sensor nodes[3]

1.1.1 Applications and Advantages of WSN

WSN has a lot of application in real-life and around the globe; people are enjoying the advantages of the WSN. These SNs are useful for various proposes such as flood detection, forest detection, environment tracking, animal tracking, forecasting, weather prediction, etc.

1. In Military application like area monitoring and tracking, these SNs are deployed onto their field of interest and are controlled by remote users.
2. In health sectors, these SNs are useful for detection of cancer cells as well as many other diseases, which humans are unable to detect.
3. The fastest growing application of these SNs are used to control traffic movement and parking monitoring.
4. Sensors are used in offices, homes and markets to detect multiple things.
5. Sensors are also used in smart vehicles to detect human for door opening or closing.

In fact, there are lot of many more applications and advantages of the WSN. Every field of life is deeply influenced by WSNs.

1.1.2 Challenges of WSN

With multiple and versatile advantages of SNs offering, WSN may pose some limitations/challenges as well like:

1. WSN possess limited storage capacity of few hundred kilobytes
2. Its processing power is authority of 8MHz
3. Finite battery lifetime

4. It has short communication range and consumes high energy during communication.

5. Costly equipments

1.2 Types of WSN

WSN has two major types in terms of communication background. One is known as Teristial WSN (TWSN) and the other one is the Underwater WSN (UWSN). Communication in TWSN is comparatively easier as compared to UWSN. Some of the major differences while routing in TWSN and UWSN environments are:

1. Size and Cost: In TWSN, air is used as a communication medium. The cost on SNs used in TWSN is inexpensive because of their small size, while in UWSN, SNs are costly due to the fact that these SNs are designed to protect them from the extreme underwater environments.

2. Deployment: Due to the challenges and cost involved, in TWSN, SNs are densely deployed as compared to UWSN where they are sparse.

3. Power: More power is required in UWSN as compared to TWSN due to greater distance and higher complexity in signal processing. Energy consumption is higher in UWSN; therefore the need of battery replacement is increased.

4. Delay: For communication, UWSN needs acoustic signals to develop communication between nodes and each generated signals propagates at approximately 1500 m/s, which causes longer delay while TWSN needs radio signals for propagation.

Moreover, in terms of communication model, WSN comprises of two main categories Homogenous WSN (HoWSN) and Heteorogenpus WSN (HtWSN). HoWSN consists of SNs having the same characteristics while SNs in HtWSN have different characteristics like different sensors and sensing range; thus there are more flexible during deployment. HtWSN provides a support for network enhancement because of the types of SNs it includes. Two categories of SNs are considered in this regard, one with high energy consumption that provides high throughput and longer sensing range. The second one is low/cheap energy nodes with limited power abilities and are not lasted for a longer time. A mixed deployment of these SNs helps to achieve a balanced energy consumption model. This is due to the death of low energy nodes, high energy nodes provide support to the network and are used for delivering the data at a higher distance. Figure. 1.4 shows a typical HoWSN and HtWSN routing model [4].

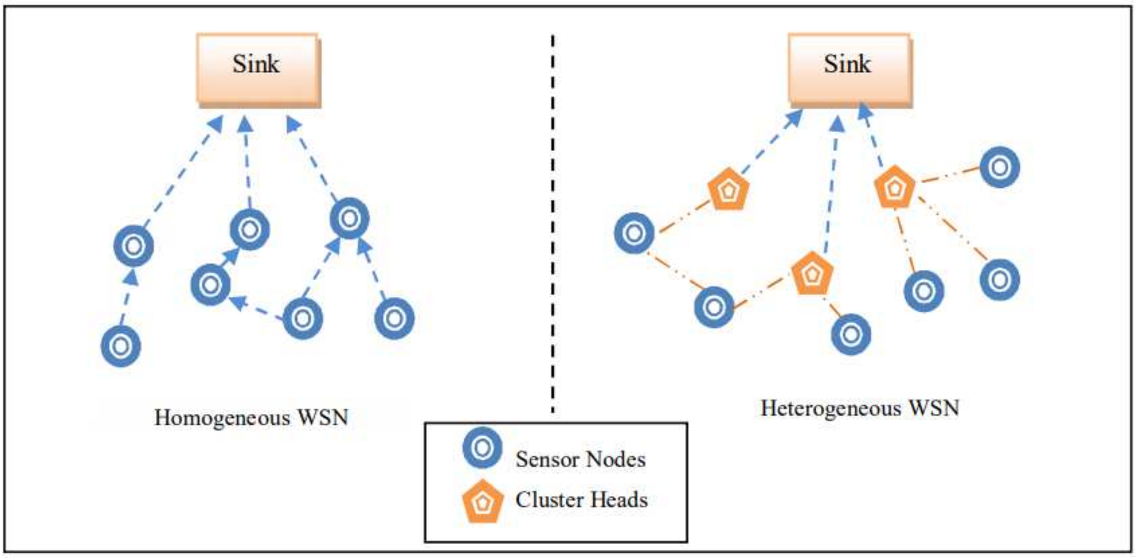

Figure 1.4: HoWSN and HtWSN model[4]

Many research models are proposed in to address the functioning of HtWSN. In order to attain the satisfactory performance, network deployment of HtWSN is complex as compared to HoWSN. Judging the behavior of SNs in HtWSN is a quite challenging task to do. However, adopting a fixed range of SNs is not a practical thing in a real-time scenario. HtWSN has to consider the network topology while deploying SNs in a network to maintain a reliable communication. In order to design a well-balanced HtWSN, high and low energy nodes lie within the sensing range of each other. Besides, the sensing range of low energy nodes is not fully covered by high energy nodes. Based on network deployment, HtWSN can be classified into the following types:

1. Link heterogeneity: In this type of heterogeneity, some SNs are linked with high-speed nodes, thus this type of network provides reliable communication because of the fact that high bandwidth is provided to high-speed nodes thus posses less data loss probability.

2. Energy heterogeneity: This type means that SNs poss different energy divisions, i.e., some posses high energy consumption while other posses low energy nodes.

3. Computational heterogeneity: In this type, some SNs are having rapid microcontroller or microprocessor and have high data storage.

4. Communications heterogeneity: This means that SNs posses different communication range, i.e., some posses high communication range while some posses low communication range.

5. Deployment heterogeneity: This type involves random nodes deployment or involving mobile nodes with normal nodes.

Efficient energy consumption is crucial while performing routing because, due to this, we can maximize performance of the network. For maintaining the network performance, nodes replacement is not an ideal solution due to certain unavoidable reasons. A fault tolerant network is also necessary in that case. Multi-path routing is a valid option to perform routing in presence of faults. Also, in WSN due to variable link capacity and high bit error rates, routing becomes unreliable. Thus, a WSN must be reliable to attain the desired results. Also, the SNs in WSN turn out to be energy exhausted due to the high amount of traffic burden; thus they die out early that leaves communication gap around the path from source to destination. By high energy exhaustion, the network lifetime tends to slow down. An efficient energy mechanism needs to be implemented, which saves the energy of nodes to maintain a stable network. Duarte-Melo [5]examines the network performance and energy consumption by considering two categories of SNs. The nodes with high-energy level belong to relay and all the nodes that are less powerful have to report their data to these relay nodes. The study of the homogenous and heterogeneous environment is the main need for designing the effective routing techniques. Mhatre [6] presents a comparative study of these type of environment and establishes a method for optimal distribution of data among different type of nodes. Other energy aware routing mechanisms [7]-[8] assume that an accurate location of a SN is said to be priori i.e., GPS is fitted in each SN that increases the node's cost.

Mostly the heterogeneous protocols are clustered based routing protocols, which use the mechanism of Cluster Head (CH) formation in the rounds. The CH is picked up on the basis of threshold. They calculate the threshold using the formula given below:

$$Threshold = \begin{cases} \frac{p}{1-p(rmod\frac{1}{p}}), & \text{if } s_i \epsilon G \\ 0, & \text{otherwise} \end{cases}$$

The term p denotes the given probability of node s_i, r is the round number and G denotes the set containing vergin nodes those were not CHs in last $\frac{1}{p_{opt}}$ rounds. Considering the above CH formula, LEACH [9] introduces a self organizing HoWSN, where SNs are arranged in clusters and to prevent the data from collision by CDMA and also TDMA based mechanisms. The decision of CHs is based entirely on the above equation 1.2. Afterwards, modification of LEACH is done, which includes LEACH-C, TL-LEACH, PEGASIS, etc. These protocols are the basis for designers in constructing a well defined HtWSN.

1.3 Objectives of the Thesis

To obtain the full advantage of various WSN applications, SNs energy is a critical issue. The sensors are usually cheap electronic devices and use energy for transfer of data and information to the sink, which definitely increases the cost of the network. So some sort of protocol is mandatory for energy efficient communication. The main objectives of this thesis are unfolded below:

- Cost reduction of the network.
- Complexity reduction.
- Maximize the stability of network nodes
- Minimize the network node die rate

1.4 Problem Statement

WSN contains tiny little devices of heterogeneous energy types, called nodes. And frequently re-energizing of batteries and re-deploying in the area of interest is not practically feasible in many of the cases. Whereas energy consumption of the nodes during sensing of environment and then sending this data to the BS is essential. Therefore nodes start dying shortly after few hundreds of rounds of packet transmission. Hence, there is a need to propose a framework which must be energy efficient so that it may result in maximum packet transmission and enhancement of network stability.

1.5 Thesis Organization

Chapter 1 presents the introduction of the WSNs, its types HoWSN and HtWSN, and application of HtWSNs. In the next chapter, related work is provided. In chapter 3, the proposed efficient communication and coordination framework for HtWSNs has been described in detail. Results of the developed protocol are shown in chapter 4. Conclusion along with future work is given in the last chapter.

Chapter 2

Literature Review

This section unfolds the brief review of existing routing protocols. There are various routing techniques that involve heterogeneity to enhance the network performance. Mostly the heterogeneous protocols use cluster based mechanism due to the fact that these protocols consist of two or more level nodes and the higher nodes among them act as a CH.

2.0.1 Requirement of CHs

Direct communication by the sensing nodes towards the BS becomes the main reason behind early dying of sensing devices. As direct communication needs more energy dissipation during transmission of packets. Hence it ultimately contributes overall less packet delivery and less stability in the network. Therefore if nodes may be organised in groups or clusters and then there does exist elected cluster head among the group or cluster then ordinary nodes may transmit data signals to respective CHs and these CHs may aggregate this received data and accordingly forward to BS. This mechanism leads towards the lower energy dissipation as transmission at shorter distances require lesser amount of energy.

An Adaptive Decentralized Re-clustering Protocol (ADRP) is introduced in [10], which selects the CHs in different rounds. The energy supply and position information of nodes is delivered towards the destination and the sink divides the network into many clusters, whereas CH is chosen in every cluster primarily on the basis of supply energy and ground position of sensor nodes. Low power nodes from every cluster deliver the sensed data towards the CH of their respective cluster. CH delivers the data that is received by node towards the sink. In the next round, new CH is selected from the CH set and the routing continues till the data is successfully delivered towards the sink. The energy of nodes is minimized in this work as re-clustering wastes a lot of energy. This proposed protocol enhances the network stability in the expense of delay as nodes wait for their turn for data transmission to the sink.

An ECRA (Energy-aware Cluster-based Routing Algorithm) is proposed in [11] to improve the overall deficiency in LEACH. According to this work, in each iteration, intra-cluster CH rotation is performed to avoid re-clustering. The ECRA-2T further improves the deficiency of ECRA by providing high tiers approach. All CHs are placed in a higher tier and the CH having the high energy than the other CH is selected as master CH of the 2nd tier. When the iterations are ended, the lower CH is re-elected and this process continues until all CHs perform data transmission successfully. A fixed size zone-based routing mechanism is proposed for HtWSN in [12], which uses the clustering technique for the election of advance nodes as a CH. It selects the minimum distance route for normal nodes to decrease the energy utilization. Moreover, it uses the state transmission to save the nodes' energy and this protocol efficiently achieves high packet delivery in the expense of network scalability.

For heterogeneity, a Selection Election Protocol (SEP) [13] is introduced, where a network consists of two levels nodes. Low state energy nodes are normal nodes and the other are those that has high energy state and called advance nodes. A SN in each cluster selects the CH based on its energy supply. The node's probability to become CH is shown in equation below referred from [13].

$$Probability = \begin{cases} \frac{p_{opt}}{1+am} & for\ normal\ nodes \\ \\ \frac{p_{opt}}{(1+a)} \times 1+am & for\ advance\ nodes \end{cases}$$

Where, m is the predefined fraction from all nodes n the optimal probability is p_{opt} . Their proposed SEP achieves high network efficiency as it does not require nodes energy knowledge after every round. The analysis of SEP applies perfectly to sparse network as well. However, in the SEP, the CH selection between two nodes are not dynamic; therefore, nodes lie far away from high energy nodes die out rapidly.

Threshold-sensitive energy efficient-sensor Network (TEEN) [14] introduces a scheme in which SNs near to CH performs data transmission to high layer CH. During CHs formation, CHs transmit two threshold values: the hard and soft values. These thresholds are the maximum and minimum values given to the trigger SNs. The TEEN minimizes the energy consumption and shows effectiveness in terms of receiving data. However, this mechanism is a good option for periodic applications because the required data may not reach to the user in a given frame of time. The performance of TEEN is later enhanced in [15], where the same network architecture is adopted except that the CH circulates attributes i.e., the threshold values. Moreover, CH aggregates the data in order to decrease the data size for transmission. The APTEEN improves the performance of LEACH and TEEN protocols. However, higher complexity involved in the implementation of threshold values, which degrades the protocol's achievements.

Avoiding the election of low-cost energy nodes as a CH, PHC [16] makes CH selection, which is based upon provided energy of given sensing nodes. Comparatively better selection of nodes which is based upon high energy levels, enhances the packet-delivery-ratio. The protocol proposed in [17] divides the network in to clusters. A CH in each cluster receives the information from the nodes of the same cluster. Data repetition is deleted in order to send the data accurately for further proceeding. A CH from one cluster delivers the information to the CH of another cluster. Thus network stability is increased by reducing the number of control messages.

A clustering mechanism with the self-organization is proposed in [18], where energy heterogenetically mechanism is applied for finding the CHs. The recharge energies of different SNs are obtained in different regions. Later, the total supplied energy of nodes is combined to enhance the selection of CH. An inter-cluster mechanism is adapted for efficient energy utilization. The Energy Balanced Clustering (EBC) algorithm maximizes the network efficiency with efficient energy utilization. However, the irregular energy distribution to nodes in each region makes the system unpredictable because CH has to choose a region having high energy level nodes.

An improved version of SEP is proposed in [19] that stabilizes the network performance more efficiently as compared to SEP. In Distributed Energy Efficient Clustering (DEEC) protocol, CH is picked up on behalf of probability that comprises of remaining power of sensing nodes and the current total network's energy at that time. Maximum supply along with remaining power of a sensor node maximizes the chances of becoming elected CH. Thus the probability of the advance nodes is high for electing as a CH, because, advance nodes have maximum energy. The probabilities for all nodes are given as [19]:

$$Ts = \begin{cases} \frac{p_{opt} E_i(r)}{(1+am)E_r} \; for \; normal \; nodes \\ \\ \frac{p_{opt}(1+a)E_i(r)}{(1+am)E_r} \; for \; advance \; nodes \end{cases}$$

where, residual energy is shown by $E_i(r)$ for node s_i in the current round r whereas E_r is the total current energy of the complete network in round r [19].

The authors propose a Developed DEEC (DDEEC) in [20] for enhancing the network's lifetime. The selection procedure of the CH is the same as SEP and DEEC, where high energy node elects to announce itself as a CH. In DEEC, the advance nodes deliver the data towards the next location. Due to data transmission by these nodes, there is high energy consumption during this process and due to this, they die out soon. With the death of these advance nodes, the network tends to slow down. The DDEEC balances the selection of CH by providing opportunities for normal nodes to become CHs. With the death of advance nodes, the normal nodes get the equal probability to become a CH. This equal probability ratio increases network performance. The probability is given as [20]:

$$p = \begin{cases} \frac{p_{opt} E_i(r)}{(1+am)E_r} \; for\ normal\ nodes\ if E_i(r) > Th_{rev} \\ \frac{p_{opt}(1+a)E_i(r)}{(1+am)E_r} \; for\ advance\ nodes\ if E_i(r) > Th_{rev} \\ c\frac{p_{opt}(1+a)E_i(r)}{(1+am)E_r} \; for\ normal\ nodes\ if E_i(r) \leq Th_{rev} \end{cases}$$

$Th_{rev} = bE_o$ b=(0,1), if $b = 0$, the protocol will work as [19] and c is a variable that defines the number of clusters.

The Enhnced DEEC (EDEEC) in [21] enhances the network's performance involving super nodes. The previous protocols rely only on two categories of nodes. In DDEEC, advance and normal nodes have an equal probability of becoming the CHs. Thus, with the increasing death rate of these nodes, EDEEC introduces a concept of threshold $T_{absolute}$ in which all the available nodes attain their respective probabilities until their energy becomes equal to the threshold energy level $T_{absolute}$. After reaching the threshold, these nodes then use the common probability given as under [21]. if $E_i(r) > T_{absolute}$, then

$$p = \begin{cases} \frac{p_{opt} E_i(r)}{(1+m(a+m_o b))E_r} \; for\ normal\ nodes\ if E_i(r) > Th_{rev} \\ \frac{p_{opt}(1+a)E_i(r)}{(1+m(a+m_o b))E_r} \; for\ advance\ nodes\ if E_i(r) > Th_{rev} \\ c\frac{p_{opt}(1+a)E_i(r)}{(1+m(a+m_o b))E_r} \; for\ normal\ nodes\ if E_i(r) \leq Th_{rev} \end{cases}$$

Here $T_{absolute} = zE_o$ [21]. If $z = 0$, the protocols works like EDEEC.

Authors in [22] develop an extended protocol of the LEACH, which forms chains of nodes to pass the data from neighboring node to sink. Only single sensing node is chosen as a forwarder node from the neighborhood table. The data gathered by selected nodes transfer from nodes to nodes in the form of chain and eventually reached to the sink. Cluster formation is avoided in PEGASIS, as it selects only one node from a chain that has high energy among other nodes. PEGASIS shows improvement in terms of network performance. However, the topology adopted by PEGASIS incurs significant overhead.

2.0.2 Benefits achieved by CHs

With passing time as WSNs evolved, now nodes usually exist in different levels of heterogeneity with respect to power. As nodes contain different levels of energy therefore these should be utilized in an optimal manners. If every node starts sending data packets directly to its BS then all nodes start dying with an illogical manner. For this a better approach may be such that sensing nodes with higher levels of energy should have higher chances of becoming CH as compared to the ordinary sensing low powered nodes.

A HEED (Hybrid Energy Efficient Distributed) mechanism has introduced in [23], that achieves four primary goals namely:

1. Network lifetime prolonging
2. Terminating the mechanism of clustering after a constant number of rounds
3. Minimization in overhead
4. Establishing well compact clusters and distributed CHs

HEED clustering mechanism picks up CHs on the basis of remaining energy power of the sensor node and the cost involved in intra cluster communication. HEED improves the network performance. However, the selection of clusters only deals with the subset of parameters, which imposes constraints on the network. However, these type of network are not reliable for entire WSN needs.

An Energy-Aware-Evolutionary routing Protocol (EAERP) was introduced in [24], that posses the major characteristics of achieving high scalability and network enhancement. It uses the dynamic clustering to save energy of sensor nodes and also increases the network lifetime in the expense of NP-hard problem that proved to be complex for a beginner. A Balanced Energy Efficient Grouping (BEEG) has been developed by Jian *et al* in [25], that forms the nodes groups based on their supply energy. BEEG operation includes grouping and transmission of data. In grouping phase of BEEG, the cluster setup mechanism is adopted, where it divides the network into clusters of different energy nodes. The division of the network helps the protocol to decrease the node dying ratio. Thus, the overall performance of the complete network has been improved. However, the protocol has to deal with the energy balancing and scalability issues, which degrades the network achievement.

Yi *et al* in [26] gives a better key distribution system to enhance the network efficiency. The mechanism consists of a sink node, CHs and SNs. Each SN has a direct linkage with CH when no more direct communication exists among the SNs. This mechanism involves three phases: in first phase, key is distributed among all the nodes, in the second and third phase, the pair is established principally based upon intra-cluster transmission and inter cluster packets communication, respectively. To secure the sensor network, each CH communicates with the other CH using an established pairwise key. This key is used for the authentication while performing communication among the CHs. The protocol achieves high packet reception in terms of increasing the energy efficiency. However, it involves more time in information sharing, which is the drawback of this protocol.

A Distance Based Cluster Protocol (DBCP) is proposed in [27], where the authors introduce two type of schemes: Homogeneous and Heterogeneous. DBCP selects CH based on its energy supply at the initial stage of network and the mean value of the distance is calculated from the source to the destination. This protocol takes full advantage of heterogeneity for better network lifetime. However, this protocol ensures the routing only in the single hop fashion; thus, increases the energy dissipation of nodes. Later, the researcher in [28] design a HtWSN network that assigns different energy thresholds to different nodes. Multi-hop communication is adopted based on the shortest distance from its neighbor node. A transition model is designed to adjust the convergence state with advance nodes. The network state of nodes comprises of energy storage and stability period. Different functions of nodes are analyzed in different regions.

Mohd *et al* introduces a Dynamic-Energy-Efficient and Secure Routing (DEESR) in [29], which constructs the routing table to store the values and sequence number generation for the selection of next hop relay nodes. It uses a trust factor that removes the malicious nodes in order to secure communication. It calculates the cost involved for each possible route and selects a route that achieves maximum cost. This protocol helps to secure the network as well as provides the network stability. The only concern in this protocol is the time involved in selecting every time forwarder nodes from routing table, which increases the chance of generation of redundant packets that effects the overall network performance.

In Hierarchical Distributed Data Classification (HDDC) in WSNs, Cheng *et al* [30] used an approach to develop a judgment tree on the basis of hierarchical distribution approach. A span tree is constructed where intermediate nodes built local classifiers and combine these classifiers with the routing paths to maximize the network performance. Later, the data originated from local classifiers are combined with pseudo data. This protocol lowers the communication overhead and helps to save the energy in the expense of reducing the network accuracy. An energy balanced routing mechanism is presented in [31], which divides the networks into a number of sectors. Every SNs in each divided sectors have a CH for the collection of data. This protocol helps to monitor the dense and sparse regions by efficient data routing and it maximizes the network lifetime. However, the main issue is that the routing mechanism is the CH movement with the water current that increases the packet loss probability.

Faisal *et al* introduce a protocol namely Zone based Stable-Election-Protocol (Z-SEP) [32] for the HtWSNs. Within Z-SEP for data packets communication clustering mechanism for data transmission towards the sink is adopted. Optimal probability against a sensing node for becoming a CH is given in [32]:

$$p_{opt} = \frac{k_o pt}{n}$$

Here the $k_o pt$ denotes the optimal clusters in the sensor network and the term n defines a number of advance sensor nodes. The main advantages of Z-SEP include:

- Energy minimization by reducing the direct communication
- Increases the stability period of a network
- Maximum throughput as compared to LEACH [9] and SEP [13]
- Z-SEP increases the hop-by-hop communication; thus increases the time for a packet reception at the sink.

2.0.3 Attainment of Better Results with improvement in Threshold Criteria

During CH selection threshold criteria may play a critically vital role. As it is simply understood the better selection results in the better outcomes in return. Here a good and comparatively a specific criteria with respect to nodes may effectively play a role in overall enhanced stability of the WSNs and better outcome in performance as more no. of data packets could be transmitted to base station.

A Balanced Energy-Efficient Network-Integrated Super Heterogenous (BEENISH) [33] is designed using four different energy level nodes. The energy balancing is acquired by selecting the nodes having the high energy as a CH frequently for data communication. The data transmission starts from high to low energy nodes. BEENISH maximizes the network performance over LEACH, SEP, DEEC and HEED. However, due to heavy data traffic on high energy nodes, their energy may equal to normal nodes. The threshold-BEENISH (TBEENISH) [34] avoids such scenario by involving sink mobility after the death of high energy nodes. Thus increases the data delivery probability and minimizes energy consumption. The authors Ekar *et al* propose an Energy Balance Mechanism (EBM) is [35] for network life maximization in corona based heterogeneous nodes model. EBM calculates the residual energy of every node in their respective corona and selects a forwarder node with high residual energy among all the nodes in their respective corona. This mechanism achieves high data delivery ratio; however, distributing extra energy among nodes is not an ideal solution for network life maximization.

Khan *et al* [36] propose a routing mechanism that uses the heterogeneity principle for lifetime maximization. Nodes near the sink deplete the excess amount of energy thus die out at the start of the network, which leaves a communication void region around the sink. With the occurrence of communication void region, no more data is delivered towards the sink. To save the energy depletion of these nodes, this protocol introduces a sleep scheduling mechanism and deployment of super nodes near to the sink. These super nodes are deployed at the boundary of the first layer that is closest to the sink. The job of these super sensing nodes is to combine the received data packets from upper layer nodes and delivers it towards the sink. The protocol elongates the network duration and reduces the energy efficiency. However, for a sparse case, this protocol failed to achieve high network performance due to the occurrence of a void hole in the greater area of the sensor network.

An energy-efficient routing mechanism was designed by the Wadud *et al* in [37], which divides the network into sectors. Different initial energies are supplied to the different groups of nodes. Nodes posses low energy values are normal nodes while super nodes are those that possess high energy values. Random deployment is adopted for normal nodes while for super nodes deployment, an arrangement is made that each region has at least 1 super node. At the start of the network, data routing is performed by normal nodes in the upper layer. When a normal ordinary node is unable to locate relay node in its communication range, it sends the ACK message to super node about its condition. The super node is moveable node that performs movement within its communication range. If a super node within its respective region receives data from normal nodes of its respective region, it gathers data for sometime and delivers it towards the next region that is close to the sink. Data transmission is improved, which helps to maximize the network lifetime.

An Energy-Efficient Unequal-Clustering (EEUC) has been proposed in [38]. They adopted the local competition for the selection of CHs. Every node poses different communication range and the range changes with the distance from sink. The nodes close to the sink have a smaller range. Furthermore, the EEUC also uses the probabilistic algorithm for the formation of the cluster. The nodes generate randomly a number, which is in between 0 and 1 to decide whether the node is going to be CH or not, respectively. If a SN decides to include itself in CH election, it becomes a tentative CH. Tentative CH then competes in their respective regions in order to become actual CH. However, this approach fails to make an impact in a practical scenario assuming a sensing region for clustering formation is not an ideal case where SNs deployment is random.

Sudha *et al.* [39] developed a protocol that aims to exploit CHs. A new mechanism is introduced that groups the nodes in the form of clusters. The traffic load of SNs is distributed into unequal size of clusters. The CH delivers the data to the sink whenever it collects the information from nodes. The selection of CH is done periodically based on the weight function that is calculated such that the number of CHs increases while routing towards the sink. This protocol ensures the maximum performance and energy efficiency. The Hybrid Energy Efficient Reactive (HEER) and Multihop HEER (MHEER) are proposed in [40] for better network performance. These protocols use the CHs selection on the behalf of their residual energy value. A major difference between the formation of clusters in both the routing protocols is that in HEER dynamic clustering is performed. However, in MHEER, a predefined fix number of clusters and CHs are taken into account. Each round generates a different number of clusters, which ensure the maximum area coverage and better stability period at the expense of network overload.

The authors of [41] improved the work of [19] by specifying proportion of each category node for three levels of heterogeneity. Whereas, Scalable Energy Efficient Scheme (SEES) [42] in favor of IoT based HtWSN integrated ambient energy-harvesting sensing nodes within zones on a few protocols including EEHDEEC protocol [41]. SEES provide better results due to introduction of undying energy harvesting nodes.

By extensive review of the literature it is deduced that formulation of clusters in WSNs is a better approach than the direct communication. Now in clusters, formulation of clusters and selection of nodes as CHs is critically important aspect. Selection takes place with certain criteria which is generally termed as threshold criteria. Therefore a better threshold criteria may assure overall betterment in performance of the WSNs.

Chapter 3

Proposed HtWSN Model

A HtWSN model has been presented in this section. It is believed, we have N number of sensing nodes, which are deployed on the ground in a random fashion within the area of M $\times$ M, as presented in figure 3.1. The SNs are always supposed to have a data to transfer to the BS. Sometime, BS is far from the SNs. However, in this network, the BS is considered at central area of the complete network region M $\times$ M. Usually, these types of network are used in military projects or other such types of implementations. Furthermore, in this HtWSN, three types of sensing nodes are considered, which are explained regarding their cost and energy consumption in Section 3.1.1.

3.1 Proposed Methodology

This section explains the proposed methodology and basic assumptions considered for proposed HtWSN, which are given below:

- BS and rest of all sensor nodes are stationary after deployment.
- A unique identity is alloted to each node.

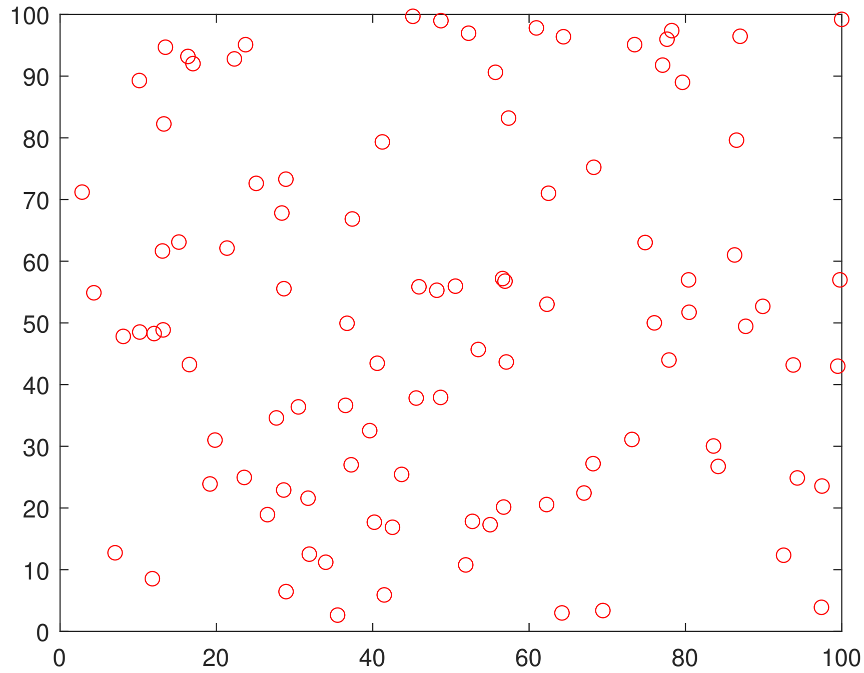

Figure 3.1: Random Deployment of 100-nodes

- Nodes are considered Global Positioning System (GPS)-less (location unaware).
- In this model, all the nodes considered with the same capabilities, i.e., communication, processing, etc.; however, they are different in terms of energies due to heterogeneity.
- Each single node is able to aggregate the data and then multiple no. of data-packets may be compressed as a solo packet.
- After nodes deployment, it is not possible to charge battery.
- This network considers only single Base Station (BS) with fixed power supply, which is located at the network's center.
- Received Signal Strength (RSS) is exploited to calculate the distance among all deployed nodes.
- All the nodes deployed in this network may be heterogenous; however, these are not chargeable.

3.1.1 Nodes Deployment and Energy Levels:

This model explains the WSN that includes three types of deployed nodes, which are categorized on the bases of the their energy levels and deployed randomly. These nodes includes: high energy nodes called costlier or super nodes, low energy nodes which are termed as normal nodes and sensing nodes which are having energy power more than these normal sensing nodes are called advanced nodes. This model focuses on the same aspect as in [41] that proportion of each category node should not be random. Rather these should be correlated and there must be a mathematics for it so that a standardization for selecting each category node may be attained. The deployed nodes along with their energy consumption and cost are explained below:

- $\Theta \times N$ shows the nodes having minimum energy, which is denoted by E_0 where $0 \leq \Theta \leq 1$.
- $\Theta^2 \times N$ presents the nodes having energy more than the normal nodes and energy is shown by E_1.
- N-($\Theta \times N + \Theta^2 \times N$) shows the nodes with greater energy than advanced and their energy is denoted by E_2.

So, there is a inequality relationship among different nodes and their energy level, is:

$$\Theta \times N > \Theta^2 \times N > N - (\Theta \times N + \Theta^2 \times N) \tag{3.1}$$

and

$$E_2 > E_1 > E_0 > 0 \tag{3.2}$$

The equations 3.1-3.2 show that the super nodes are deployed minimum in numbers due to their high energy consumption and cost. To make network cheaper maximum number of normal nodes are deployed due to their minimum cost and minimum energy consumption. In this way, our proposed network model has minimum cost along with minimal energy consumption. Furthermore, grand total energy of the entire network can be obtained through following mathematical expression: 3.3.

$$(\Theta \times N) \times E_0 + (\Theta^2 \times N) \times E_1 + (N - (\Theta \times N + \Theta^2 \times N)) \times E_2 \tag{3.3}$$

The proposed model presents a three different types of nodes which are different on the bases of their energy and cost. It is verified through summing up all types of nodes. Overall increase in energy of network with respect to normal nodes may be computed from 3.3 i.e

$$Increment factor = \big(\Theta + \Theta^2 \times \frac{E_1}{E_0} + (1 - \Theta - \Theta^2) \times \frac{E_2}{E_0}) \tag{3.4}$$

3.2 Proposed T-EEHDEEC Heterogenous Protocol

This section presents the discription of our proposed T-EEHDEEC protocol. It is important to describe the DEEC [19], EEHDEEC [41] and TBEENISH [34] before explanation of our proposed T-EEHDEEC protocol. In DEEC, distribution of each category node in three or more categories is just random.Whereas, EEHDEEC gave optimal proportion of the each category node with respect to each other in three level of heterogenity. It also provides the upper and lower limit of each category of nodes but it used same threshold as of DEEC protocol. And in TBEENISH threshold was improved but underlying distribution of nodes was not as good as of EEHDEEC. However, we adopted the procedure of DEEC, node distribution mechanism from EEHDEEC and proposed our own threshold criteria which outperformed state of the art protocol TBEENISH from multiple aspects.

Our proposed T-EEHDEEC follows the process of CH selection as of [19] but with weighted

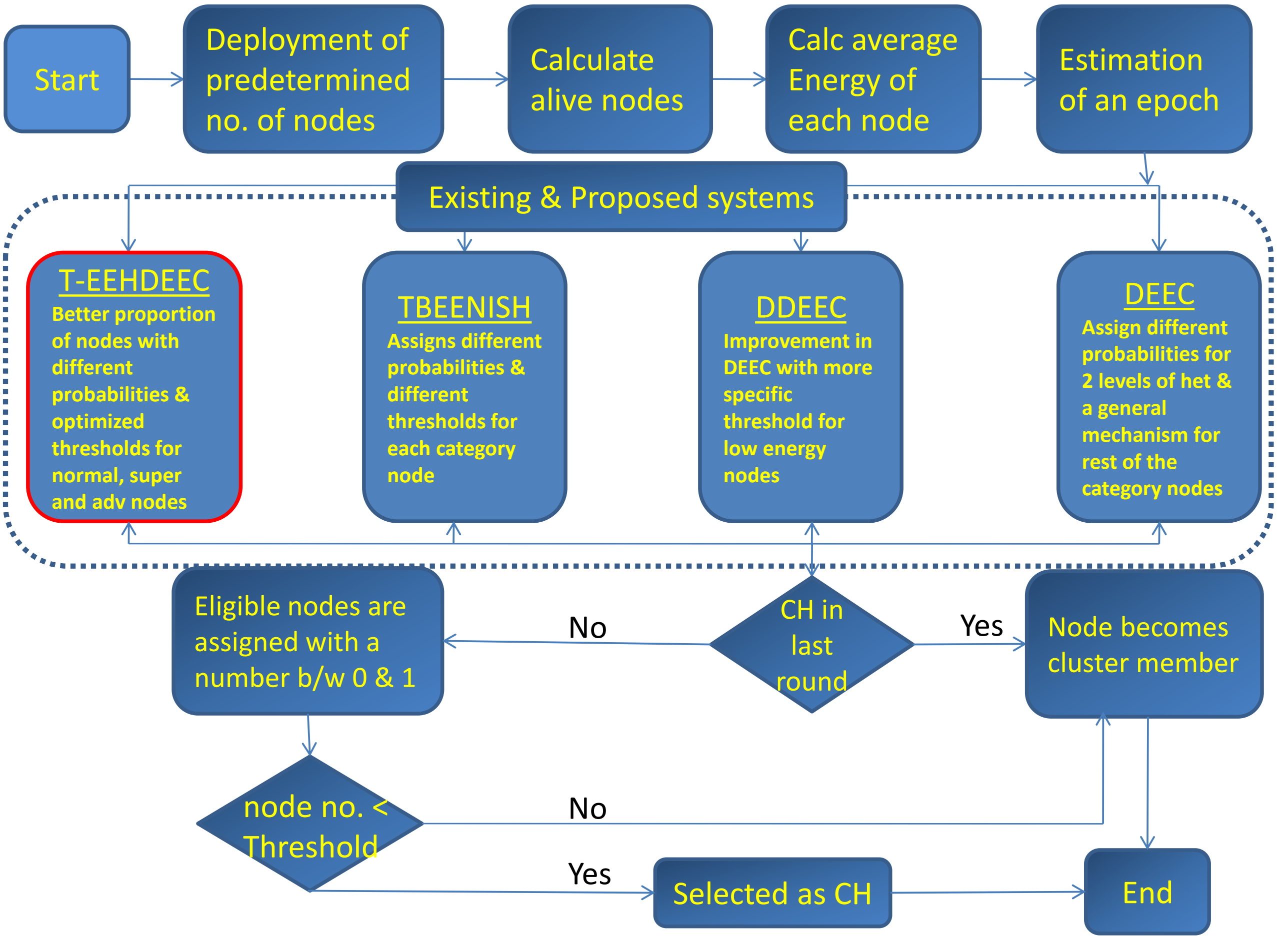

Figure 3.2: Flowchart of existing and proposed HtWSN network models

probabilities. These weighted probabilites preserves the advantage of node distribution with respect to energy levels. Hence super node have higher probability than the normal node. Average number of CH has been considered in every round of HtWSNs [41] as $N \times p_{normal} \times Incrementfactor$. Furthermore, every node may become CH once in every $R_i = \frac{1}{P_{weighted}}$ rounds, where $P_{weighted}$ shows the optimal probability of every node with respect to its category which might be p_{normal},$p_{advance}$ or $p_{super}$to become CH. The R_i shows the round, where i^{th} node became CH.

According to our proposed model, the weighted probabilities are calculated p_{normal}, $p_{advance}$

and p_{super} for normal, advance and super nodes, respectively, by the equations 3.5-3.7.

$$p_{normal} = \frac{P_{optimal} \times E_i(r)}{(\Theta + \Theta^2 \times \frac{E_1}{E_0} + (1 - \Theta - \Theta^2) \times \frac{E_2}{E_0}) \times E(r)} \tag{3.5}$$

$$p_{advance} = \frac{P_{optimal}(1 + \alpha) \times E_i(r)}{(\Theta + \Theta^2 \times \frac{E_1}{E_0} + (1 - \Theta - \Theta^2) \times \frac{E_2}{E_0}) \times E(r)} \tag{3.6}$$

$$p_{super} = \frac{P_{optimal}(1 + \beta) \times E_i(r)}{(\Theta + \Theta^2 \times \frac{E_1}{E_0} + (1 - \Theta - \Theta^2) \times \frac{E_2}{E_0}) \times E(r)} \tag{3.7}$$

Moreover, DEEC [19] and EEHDEEC [41] use the same threshold for CH selection; however, TBEENISH [34] improved their threshold by incorporating three additional parameters which are Residual energy of sensing node, optimal no. of CHs and Average energy of a sensing node. Whereas our proposed novel threshold for CH selection out performs TBEENISH protocol. The proposed novel threshold is presented in equations 3.8-3.10.

$$Threshold_{normal} = \frac{p_{norml}}{1 - p_{normal} \times (r\ mod \frac{1}{p_{normal}})} \times RE_{normal} \tag{3.8}$$

$$Threshold_{advance} = \frac{p_{advance}}{1 - p_{advance} \times (r\ mod \frac{1}{p_{advance}})} \times RE_{advance} \tag{3.9}$$

$$Threshold_{super} = \frac{p_{super}}{1 - p_{super} \times (r\ mod \frac{1}{p_{super}})} \times RE_{super} \tag{3.10}$$

Where, r and RE show the rounds and residual energy of the i^{th} node respectively. RE of

i^{th} node is calculated with this mechanism:

$$RE_{node} = \begin{cases} RE_{node} - l \times [(ETX + EDA) + (\varepsilon fs \times d^2)],\ if\ d < d_o \\ RE_{node} - l \times [(ETX + EDA) + (\varepsilon mp \times d^4)],\ if\ d > d_o \end{cases}$$

Here RE_{node} represents residual energy of a node which may belong to any energy category, l represents packet size, EDA is energy dissipation during data aggregation, ETX is energy required for making sensing device ON for transmission or reception of signals whereas, mp and fs are dimension-less path design, and d shows distance from sensing node to CH or BS.

Chapter 4

Results and Analysis

Here in this part of my thesis, the simulation setups and obtained results have been uncovered to show the superior performance of the our proposed protocol. For comparative analysis, existing schemes have also been implemented. According to our proposed model, 100 heterogenous nodes have been deployed in the area of 100m $\times$ 100m, randomly. The network parameters that are considered to perform the simulation are presented in table 4.1. The simulation results and their discussion are discussed below.

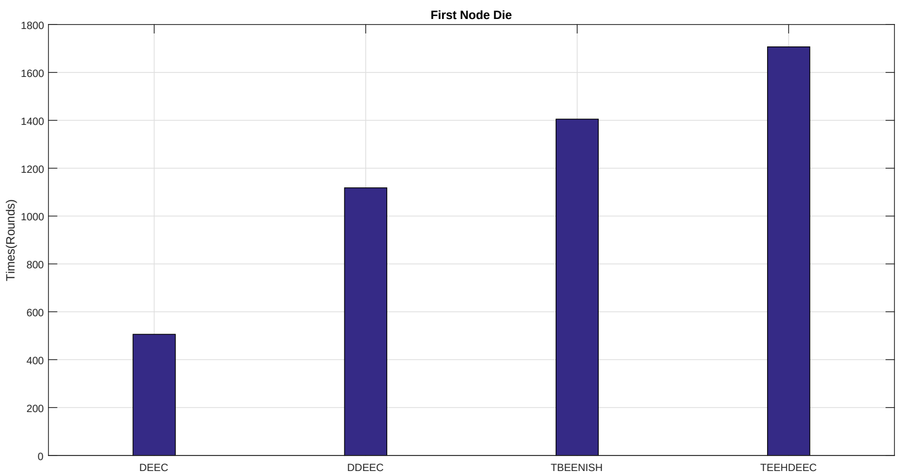

Figure 4.1: FND of Protocols

The figure 4.1 presents the First Node Die (FND) status of the our proposed and exist-

Table 4.1: Parameters for simulations

Detail	**Value**
No. of sensing nodes	100
Size of network	100 m, 100 m
Message size	4000 bits
Node initial energy	0.50 J
Position of base station	50m, 50m
Threshold distance	70 m
Radius of cluster	25 M
Power consumption of amplifier to transfer to higher distance	0.0013 pj/bit/m4
Power consumption of amplifier to transfer to lower distance	10 nj/bit/m2

ing protocols. It is clearly depicted in this figure that FND in round 1711 using our proposed protocol. However, by using the existing state of the art TBEENISH protocol, the FND in round 1403. So, our proposed protocol T-EEHDEEC shows high performance. Stability of the Network is dependent upon the alive nodes and in our proposed model Network remains completely stable till 1711 rounds whereas in existing system stability of the Network compromised in just round 1403. That is achieved through optimal employment of the available nodes.

In addition to Table 4.1 basic parameters we used Θ, α β for fraction of normal nodes and additional energy proportions in our proposed T-EEHDEEC protocol which is 0.51, 0.92 1.15 respectively in simulations. Similarly we took m=0.5 m_0=0.3 for derivation of fraction of advance super nodes along with enhanced energy levels which are 1.8 and 2.4 respectively for TBEENISH protocol mechanism. Keeping equal no. of nodes with equal grand total energy of the network we performed simulations for the performance testing of the proposed and existing systems.

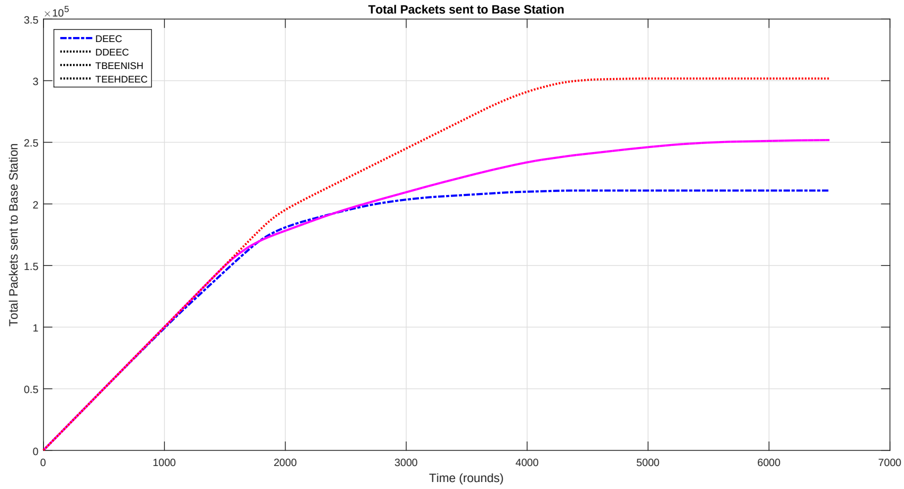

Figure 4.2: Packets sent to BS

Total packets transferred to BS with respect to simulation time (rounds) by different protocols are presented in Figure 4.2. We can easily distinguish better performance of our proposed protocol T-EEHDEEC from rest of the protocols especially with state of the art TBEEBINSH protocol. T-EEHDEEC sent more data to BS as compared to existing TBEENISH scheme which is 302614 and 251823 packets respectively.

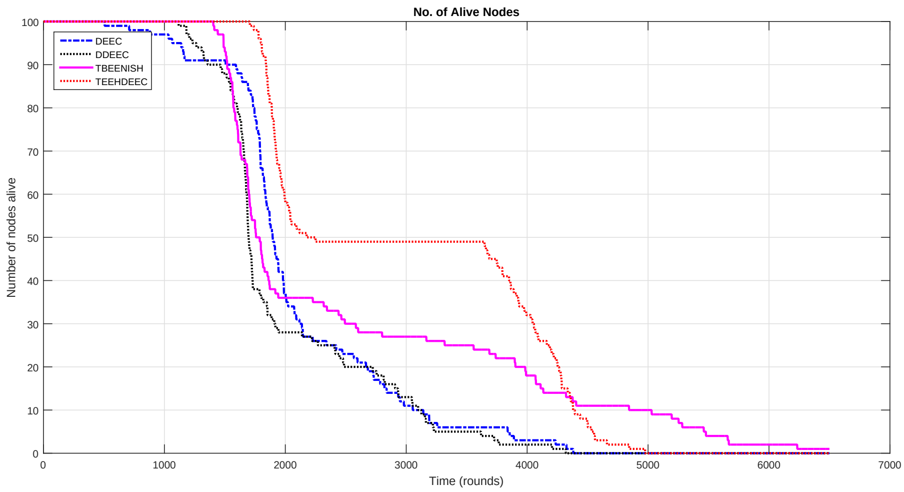

Figure 4.3: Alive nodes during Rounds

A visual description of alive and dead nodes may be seen in Figure 4.3 Figure 4.4 correspondingly. Which shows our proposed model is far superior than the existing protocols. At moment the first node dies reliability of the network is gone. No one can imagine the criticality of the dead node due to the random deployment.

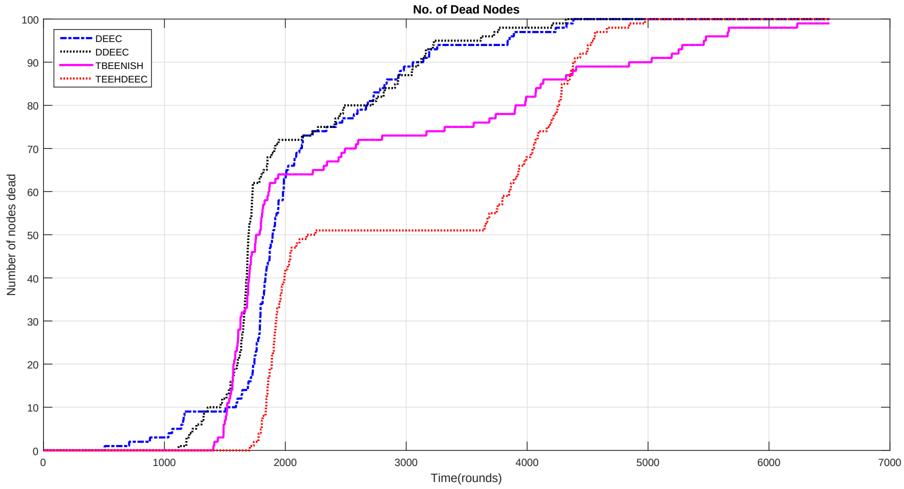

Figure 4.4: Dead nodes during Rounds

If we observe number of CHs during each round even then distribution by proposed model is more rational than rest of the models as shown in Figure 4.5. Due to this rational approach appropriate number of CHs always exist in proportion to alive nodes, resultantly system has more liberty to send data packets through CHs instead of direct communication to BS.

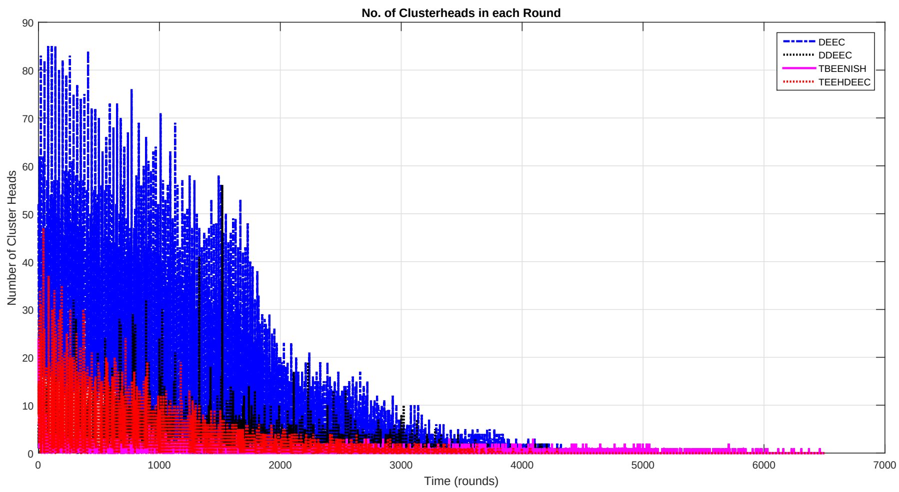

Figure 4.5: Number of CHs during Rounds

A brief comparison of proposed model with respect to ages of the nodes as given in Table

Table 4.2: A Comparison: Ages of Nodes

Protocols	**1st node Death**	**20th node Death**	**80th node Death**	**All node Died**
TBEENISH	1403	1557	3954	6380
T-EEHDEEC	1711	1844	4354	4983

4.2 clearly depicts proposed model enhances stability and makes the network more reliable for longer period of time. In case of first node T-EEHDEEC achieved huge improvement.

After comparing different aspects of T-EEHDEEC with other protocols and finding our model a better approach, now we will show comparison of our own system in a different way. As we have improved two main features of TBEENISH which made it a new model and we have given it a new name as T-EEHDEEC. Therefore we are going to make a comparison in such a manner that first we showed TBEENISH's results then we changed its distribution of proportion of nodes as per our proposed model and acquired results and finally we also changed its threshold as per our own proposed model and obtained results.

On adding each new feature to TBEENISH protocol we obtained better and better results. First we used T-EEHDEEC's distribution proportion of nodes and results showed it outperformed raw TBEENISH. Then we improved it by adding our own threshold and it further improved its results which are shown in subsequent Figures.

First node dies in TBEENISH at 1420 rounds and at 1624 when we used our proposed model's distribution of nodes whereas once we used our proposed model's threshold then first node died at 1708 rounds.These results are depicted in Figure 4.6. Similarly other achieved results showed that our proposed model is a superior model.

Overall better performance by our proposed model was achieved due to better distribution of nodes with respect to their categories and with better power management by the

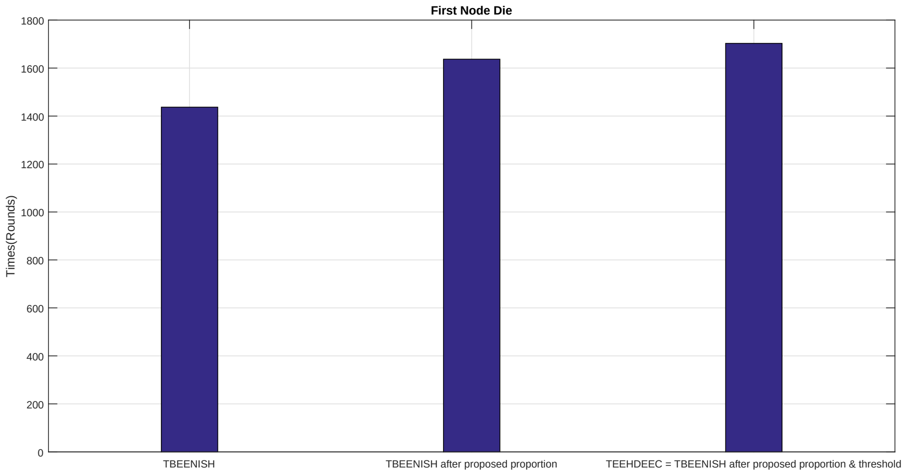

Figure 4.6: First Node Dies

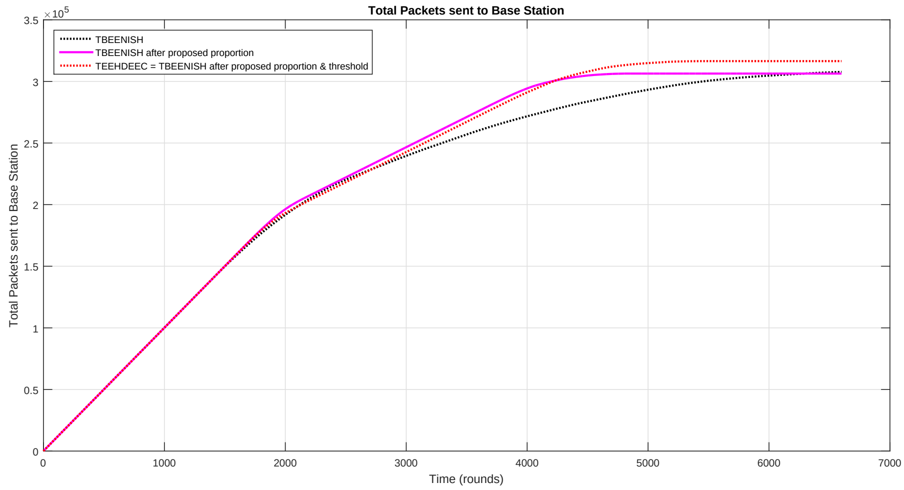

Figure 4.7: Packets transmitted to BS

help of appropriate no. of CHs in every round. One the other hand proposed novel threshold criteria was also the main reason which consequently gave better results.

Chapter 5

Conclusion and Future Work

This sections presents the conclusion of my thesis along with findings. Furthermore, the possible future directions are also uncovered in this section.

5.1 Conclusion

In this thesis, an energy efficient communication and coordination framework has been developed for HtWSN. Specifically, this thesis focuses on efficient data/ information communication with optimized energy cost. For this purpose, three types of nodes are considered in this work for data communication. An energy efficient communication protocol namely T-EEHDEEC has also been proposed, where a better node distribution mechanism and a better threshold policy has been adopted, which gave better results and consequentially performance and stability of the network enhances. Furthermore, to affirm the legitimacy and productiveness of our proposed T-EEHDEEC scheme with existing schemes, simulations are carried out. The state-of-the-art scheme named TBEENISH has been also implemented for comparison purpose. Simulation results present that the T-EEHDEEC shows higher performance in terms of energy cost, FND and packets sent to base station. Moreover, the proposed protocol T-

EEHDEEC enhances the stability of the network by 21.95 % as compared to the base scheme. Our proposed protocol also offers minimal energy cost as from network stability aspect FND very late.

5.2 Future Work

In the future, the benefits of the proposed T-EEHDEEC may be enhanced by incorporating 'n' number of heterogeneity levels. On the other hand, larger area may be covered by incorporating energy harvesting nodes on certain distances or in grids form. These incorporated nodes may act as subsidiary BSs or as rely stations for further transmission to targeted BS. Hence scalability may be achieved for deployment of this system in any IoT based environment.

Furthermore, the consideration of mobility based HtWSN nodes in the present scheme to enhance its productiveness will be another direction of our research.

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